Last time

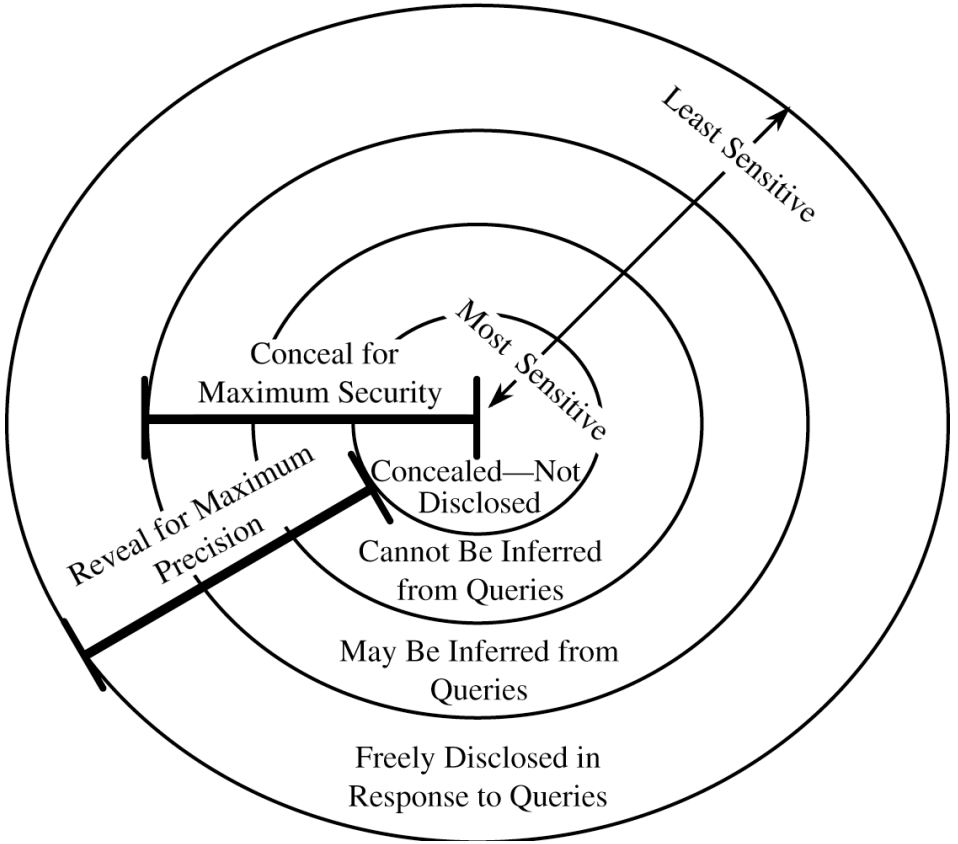
- Finish OTR
- Database Security
  - Introduction to Databases
  - Security Requirements
  - Integrity
  - Auditability, Access Control, and Availability

This time

- Database Security
  - Data Inference
  - Statistical Inference
  - Controls against Inference
- Multilevel Security Databases
  - Separation
  - Integrity Locks
  - Designs of MLS Databases

Security vs. Precision

- Security: Forbid any queries that access sensitive data, even if (aggregated) result is no longer sensitive
- Precision: Aggregated result should reveal as much non-sensitive data as possible



Data Inference

- Derivation of sensitive data from non-sensitive data
- Direct attack
  - Attacker issues query that directly yields sensitive data
  - Might obfuscate query to make it less obvious
    - `SELECT salary FROM staff WHERE lastname = 'Adams' OR (sex != 'M' AND sex != 'F')`
- Indirect attack
  - Infer sensitive data from statistical results
    - As released by governments or pollers
- Data inference is related to data aggregation
  - Derivation of sensitive data from less sensitive data

Statistical Inference Attacks

- Sum
  - Leaks sensitive data if sum covers only one record or if attacker can control set of covered records
    - `SELECT SUM(salary)`
    - `SELECT SUM(salary) WHERE lastname != 'Adams'`
- Count
  - Useful in attack above
- Mean
  - sum = count * mean
- Median
  - Intersecting medians might leak sensitive data
  - See text for example

Tracker Attacks

- Focus on queries of type `SUM` or `COUNT`
- Assume that DBMS refuses to answer a query if number of matching records is smaller than *k* or larger than *N-k* (Why?)
  - *N*: number of records in database
- A tracker *T* is a query whose result matches between *2k* and *N-2k* records
  - DBMS will answer *T* (and *not T*)
- Assume that there is a query *C* that DBMS refuses to answer since it matches fewer than *k* or more than *N-k* records

Tracker Attacks (cont.)

- Let *q()* be the result of a query and *S* the set of all records
- Using Venn diagrams, we can show that
  - *q(C) = q(C or T) + q(C or not T) – q(S)*
  - Use right-hand side for computing *q(C)* if *q(C)* matches fewer than *k* records
  - *q(C) = 2 * q(S) - q(not C or T) - q(not C or not T)*
  - Use right-hand side for computing *q(C)* if *q(C)* matches more than *n-k* records
- In general, simple logic or linear algebra might allow an attacker to convert a forbidden query into multiple, allowed queries

Controls for Statistical Inference Attacks

- Apply control to query or to data items
  - As seen, former is difficult
- Suppression and concealing are two controls applied to data items
- Suppression
  - Suppress sensitive data from result
- Concealing
  - Answer is close to actual value, but not exactly

Controls (cont.)

- n-item k-percent rule
  - If there are n records and they represent over k percent of reported result, omit these records from result
  - However, omission itself might leak information or omitted value could be derived with other means
- Combined results
  - Report set or range of possible values
- Random sample
  - Compute result on random sample of database
  - Need to use same sample for equivalent queries

Controls (cont.)

- Random data perturbation
  - Add or subtract small random error to/from each value before computing result
  - Expectation is that statistical properties are maintained

- Query analysis
  - Maintain history of user's queries and observe possible inferences
  - Costly, fails for colluding users

Aggregation

- Building sensitive results from less sensitive inputs, typically from different sources (e.g., people)
- Aggregation can take place outside of a DBMS, which makes it difficult to control
  - People talking to each other
- Closely related to data mining (see later), where information from different databases is combined

Multilevel Security (MLS) Databases

- Support classification/compartmentalization of information according to its confidentiality/integrity
  - Two levels (sensitive and not sensitive) might not be sufficient
- At element level if necessary
  - Salary might be sensitive only for some employees
  - Other information in employee's record might not be sensitive
- In an MLS database, each object has a classification and maybe a compartment
  - Object can be element, aggregate, column, or row

*-Property

- Implementing the *-property in an MLS database is difficult
  - User doing a write-up though user cannot read data at higher level (Blind writes)
  - Write-downs need a sanitization mechanism
  - Trusted processes that can do anything
- DBMS must have read and write access at all levels to answer user queries, perform back-ups, optimize database,…
  - Must trust DBMS

Confidentiality

- Depending on a user's level, he/she might get different answers for a query
  - Less precision for low-level users
- Existence of a record itself could be confidential
- Keeping existence hidden can lead to having multiple records with the same primary key (polyinstantiation)
  - Admin notices that there is no record for Bob Hill and creates one
  - However, Bob Hill is a secret agent, so there already is a record, which admin cannot see
  - DBMS must allow admin's request, else admin would get suspicious

Partitioning

- Have separate database for each classification level
- Simple, often used in practice
- Might lead to data stored redundantly in multiple databases
- Doesn’t address the problem of a high-level user needing access to low-level data combined with high-level data

Encryption

- Separate data by encrypting it with a key unique to its classification level
- Must be careful to use encryption scheme in the right way
  - E.g., encrypting the same value in different record with the same key should lead to different ciphertexts
- Processing of a query becomes expensive, many records might have to be decrypted
  - Doing the processing directly on the encrypted data is an active research area

Integrity Lock

- Provides both integrity and access control
- Each data item consists of
  - The actual data item
  - A sensitivity label (maybe concealed)
  - A cryptographic signature (or MAC) covering the above plus the item's attribute name and its record number
- Signature protects against attacks on the above fields, such as attacks trying to modify the sensitivity label, and attacks trying to move/copy the item in the database
- This scheme does not protect against replay attacks

Integrity Lock (cont.)

- Any (untrusted) database can be used to store data items and their integrity locks
  - Locks can consume lots of space (maybe multiple locks per record)
- (Trusted) procedure handles access control and manages integrity locks
  - E.g., updates sensitivity level to enforce *-property or re-computes signature after a write access
  - Expensive
- Have to encrypt items and locks if there are other ways to get access to data in database
  - Makes query processing even more expensive

Trusted Front End

- Front end authenticates a user and forwards user query to old-style DBMS
- Front end gets result from DBMS and removes data items that user is not allowed to see
- Allows use of existing DBMS and databases
- Inefficient if DBMS returns lots of items and most of them are being dropped by front end

Commutative Filters

- Front end re-writes user query according to a user's classification
  - Remove attributes that user is not allowed to see
  - Add constraint expressing user's classification
- Benefits from DBMS' superior query processing capabilities and discards forbidden data items early on
- Front end might still have to do some post processing

Distributed/Federated Databases

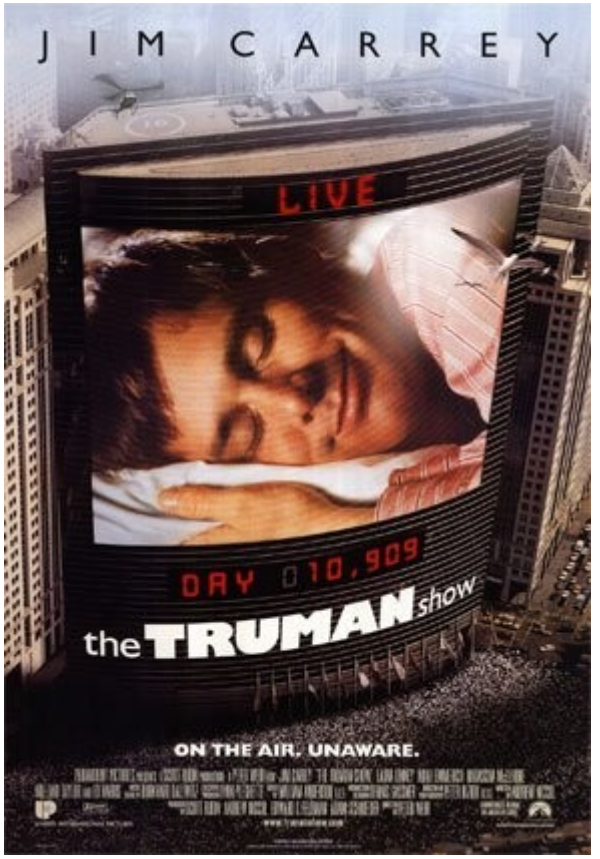
- Based on partitioning
- Front end forwards user query only to databases that user can access based on classification
- Front end might have to combine the results from multiple databases
  - Complex process, front end essentially becomes a DBMS
- Doesn't scale to lots of classification levels

Views

- Many DBMS support views
- A view is logical database that represents a subset of some other database
  - `CREATE VIEW foo AS SELECT * FROM bar WHERE…`
- Element in view can correspond to an element in underlying database or be a combination of multiple elements
  - E.g., their sum
- Views can be used for access control
  - A user's view of a database consists of only the data that the user is allowed to access
  - Hide attribute/row unless user is allowed to access at least one element, set to UNDEFINED any elements that user can't access

Truman vs. Non-Truman semantics

- Truman semantics: the DBMS pretends that the data the user is allowed to access is all the data there is
  - Like “The Truman Show”
  - All queries will succeed, even if they return imprecise results
- Non-Truman semantics: the DBMS can reject queries that ask for data the user is not allowed to access
  - Any queries that succeed will produce precise answers
  - Some queries will fail



Recap

- Database Security
  - Data Inference
  - Statistical Inference
  - Controls against Inference
- Multilevel Security Databases
  - Separation
  - Integrity Locks
  - Designs of MLS Databases

Next time

- Data Mining
  - Integrity and Availability
  - Privacy and Data Mining
  - Privacy-Preserving Data Mining